Towards a methodology for flexible urban design: designing with urban patterns and shape grammars

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Abstract.

Traditional urban plans use definitive design systems, without the flexibility required to deal with the complexity and change that characterize contemporary urban societies. To conceive urban plans with increased flexibility, it is proposed a shape grammar-based design methodology capable of producing various design solutions instead of a single rigid layout. In this approach, the plan is a design system encoding a set of alternative solutions, rather than a single, specific solution. This methodology was developed based on the analysis of existing plans and on a series of experiments undertaken within the controlled environment of design studios. Results show that shape grammars produce urban plans with non-definitive formal solutions, while keeping a consistent design language. They also provide plans with explicit and implicit flexibility, thereby giving future designers a wider degree of freedom. As a result, they are particularly appropriated to deal with complexity and change throughout the legal lifespan of the plan. Finally, they provide students with a concrete methodology for approaching urban design, fostering the development of additional design skills.

1. Introduction

Traditionally, urban plans are developed following methodologies aimed at the production of a single layout representing a rigid, definite solution. In addition, plans are centered on the definition of tight and interdependent urban parameters that tend to reduce design to a direct formalization of such parameters. However, legislation constrains neither design nor its representation to such an extent that they forbid design flexibility. In fact, It does not impose specific representational devices, nor does it imply any specific way of designing. We believe that the resulting rigidity derives from an unconscious repetition of procedures, probably because this makes it easier to design and to communicate design intents, given the lack of a design methodology that supports flexible urban design.

The increased complexity and change that characterize contemporary urban societies require a more flexible approach to urban design. According to Friedman, (1977) plans should prescribe a clear development vision at a very general and larger scale while being flexible regarding the design of specific urban spaces. Ascher (2001) mentions, “new urbanism should be a flexible urbanism, aesthetically
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opened, reflexive, with active participation and, formally speaking, an urbanism of devices able to elaborate and negotiate solutions rather than drawing specific plans.” This paper deals with the problem of creating alternative approaches to urban design that can lead to flexible urban plans. To accomplish this goal, we propose a design methodology based on the use of urban patterns (Alexander, 1977) and shape grammars. (Stiny and Gips, 1972) The idea is to create a design system instead of the usual single design. The system will permit the generation of alternative solutions to respond to changes in the context during the legal lifespan of the plan, while maintaining the same ordering principles and aesthetic coherence.

2. The use of shape grammars in urban design and in teaching

A shape grammar is a set of shape transformation rules that apply recursively to an initial shape to generate a language of designs. Shape grammars are simultaneously descriptive and generative and so they can be used as an analytical tool to describe the formal structure of a corpus of existing designs, to determine whether other designs are in the same language, and to explain how to generate new designs. They can also be used as a synthetic tool to create new languages of design. In both cases they facilitate the automatic generation of designs. Although shape grammars were considerably used in architecture, their use in urban design was limited until a few years ago, both for analytical and generative purposes. The first mention to the use of shape grammars for urban design is found in the work of Brown and Johnson, (1984) who analyzed the evolution of London mediaeval city blocks. Although they use graph-based depth analysis, they state that a shape grammar could be developed to describe the evolution of the urban fabric. It took twelve more years for the first analytical grammar to be developed for urban design by Teeling (1996), who concentrated on the geometrical evolution of urban grids by inferring the polygonal subdivisions that originated the final urban structure. Teeling demonstrated that shape rules could replicate the original urban form but also generate new ones with similar features. Recent developments, such as those of Parish and Muller, (2001) Mayall and Hall, (2005) and Duarte et al. (2007) among others have shown the growing interest in the potential of shape grammars to deal with urban design problems. The present paper describes work that has been developed since 2001 to identify the potential and opportunities for using shape grammar as a synthetic tool in urban design. It complements and details work presented in an earlier paper. (Beirão and Duarte, 2005)
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Part of the difficulties in the use of shape grammars for urban design occurs because it is not just a matter of recursive shape transformation but requires one to take into account complex phenomena, such as urban policies, social dynamics, as well as territorial features like topography, climate, and so on. The semantic discourse and technical effectiveness in urban design arise from the recognition of political, social, and territorial contexts and so having a way of describing these contexts and relating them to shape transformation is necessary for developing effective urban grammars. This semantic problem has already been pointed out by Fleisher (1992) as a flaw of architectural shape grammars. Duarte (2005) showed the problem could be solved by combining Stiny’s description grammars (1981) with shape grammars to produce semantic descriptions of designs that are adequate to the context and then generate design solutions accordingly. This strategy of linking contextual features to design decisions can be used in urban design and it seems particularly appropriate to deal with its complexity, as shown by ongoing research. (Beirão et al., 2009)

The use of shape grammars in teaching also has been somewhat limited. In 1980 Stiny proposed a program for using grammars in design education, (1980) and experiments in this area were developed by Ulrich Flemming (1987) at Carnegie Mellon University and Terry Knight (1999), at MIT. In 2001, a program for using shape grammars in the teaching of urban design at the undergraduate level was set up at the TU Lisbon Faculty of Architecture. In this case, shape grammars were introduced in a methodology to teach urban design in what would otherwise be a standard studio. In 2002, the concept of pattern language (Alexander et al., 1977) was added to the methodological approach as a means to define design goals. The use of patterns has shown to help defining meaningful grammars and adequate development visions. To the extent of our knowledge, this was the first program of this kind, and several studios were taught since the program was set up. This paper focuses on the studios undertaken in the academic years of 2002-2003 and 2003-2004, when studio work and its results were closely monitored to formalize the methodology and assess results. It outlines the methodology, discusses results, and describes posterior refinements introduced in the years that followed.

3. Research methodology

As said above, our goal is to devise a methodology for approaching the urban design process using urban patterns and shape grammars to deliver a system of alternative solutions instead of a single, definitive solution.
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The research methodology used for developing the design methodology encompassed three steps. In the first step, we analyzed existing urban plans to infer and sketch the methodology. In the second step, we asked a group of students in the fifth year of the professional architecture program to use the sketched methodology and shape grammars for developing a rule-based system for designing of new town. The analysis of results consolidated the methodology and laid down the basis for another experiment in the following academic year. This experiment was the third research step, and it consisted in asking students to devise the expansion plan of an existing town as a rule-based system and then testing it by asking other students to develop a detail plan for a smaller area of the larger, expansion plan. In the detail plan, students could use the rules of the larger plan to generate an alternative solution and had to come up with new rules to define material aspects. Results were then analyzed with the goal of assessing and refining the methodology. The outcomes of these research steps are described below.

3.1. Step 1: Analysis of existing plans – inferring a design system

By analyzing four urban plans by different authors, it was possible to identify a recurrent methodological approach. These plans were Álvaro Siza’s Malagueira plan in Évora (Figure 1), Adrian Geuze’s plan for Borneo-Sporenburg in Amsterdam (Figure 2), and Chuva Gomes’s plans for Quinta da Fonte da Prata at Moita and for the extension of Cidade da Praia in Cape Verde (Figure 3). Other plans were considered during this study, although they were not analyzed in depth. The reasons for choosing these plans were as follows. First, they were designed by renowned architects, which potentially guaranteed high standards of quality. Second, there were publications on the plans and it was possible to interview the authors to collect additional information for reconstructing their design processes and unveiling the design methodologies. Preliminary analysis revealed that these plans possessed qualities in terms of planning efficiency and latent flexibility. A design methodology encompassing four levels of decreased scale and increased detail was sketched based on the analysis. The four levels are present in the four plans and they constitute part of an algorithm-like approach to design that takes preexisting contextual features into account to define main geometric guidelines, basic grids, urban blocks and plots, and material features. These aspects are ordered according to scale and not necessarily to design sequence, although a sequential logic is latent in their use and effectively present in the studied cases. Analysis revealed that designers were so systematic in the elaboration of the plans that it would be straightforward to encode them into shape grammars.
An old essay by Molteni (1977) on Siza’s work emphasized that language and site features are important aspects of his design process and provided valuable information on how to interpret and incorporate them in urban design. The analyses of Siza’s drawings strongly support this link between preexisting site conditions and design proposal. A large number of articles on Geuze’s plan for Borneo-Sporenburg discussed how Geuze approached the theme of flexibility in this plan (Gausa, 1998; Geuze, 2001). Specifically, these articles described very accurately the generation of the underlying urban grid (Figure 2) and how Geuze generated non-deterministic compositions of urban blocks using a subtraction process. Designs would change depending on the number of plots and on the interpretation of the subtraction process. This is an interesting example of the flexible design of urban blocks and it reveals. Rules were very clearly defined in simple graphic schemas. In Chuva Gomes’s case, the comparison of his plans for different sites made it possible to identify the same design principles applied to different contexts, thereby revealing the persistence of specific design rules in the designer’s method, and suggesting that a rule-based design system can be used for generating solutions for different design contexts. These design principles came out in interviews with the architect who described a clear methodology for approaching urban design. His description was very close to the one presented below and is clearly present in his plan for Praia. (Figure 3)
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**Figure 1.** Álvaro Siza, Malagueira plan, Évora, Portugal. Sequence showing Siza’s design steps: a – initial site; b – preexistences used to generate the plan – neighbourhoods, roads, pedestrian pathways and waterline; c – main compositional geometries; d – secondary geometries and street grid; e – final plan with blocks and plots.
Figure 2. Adrian Geuze (west 8), Borneo-Sporeburg plan, Amsterdam, Netherlands. Sequence shows: a – limits; b – grid definition; c – viewpoints and landmark buildings; d – grid subtraction for landmark buildings; e – final plan with plots. 30 to 50 percent of plot volume has been subtracted to guarantee natural lighting and ventilation.
In summary, results in this research step revealed that, despite variation in style from one designer to another or changes in the context from one plan to another by the same designer, different designers used a similar approach that encompassed four levels:

1) Territorial landmarks: Rules on this level deal with the understanding of the territory and are targeted at singling out elements in the territory and marking them as important references for design generation. It is recognizable in each project the integration of preexisting elements, such as roads, paths, constructions, waterlines, or features drawn from the territory’s morphology such as ridges, valleys, and so on. In a way or another, these elements were subsequently used to define limits, basic geometries, or landmarks.

2) Basic geometries: These rules are divided into two subsets, one to lay down the main geometric guidelines of the plan, and the other to generate urban grids. The first set is aimed at defining relations among preexisting elements, selected as references on the previous level, to structure the main geometric elements of the plan. The second rule set defines strong geometric principles, usually grids, which are
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responsible for ordering the plan. The later rules are responsible for some of the most deterministic moves of the design process.

3) Urban units: These rules are used to define urban units such as neighborhoods, blocks, plots, volumes, as well as clusters of any of these units. This third level is the most important in the characterization of urban space and the type of city life proposed by the plan. This level was clearer in the cases of the Borneo-Sporenhburg plan by Geuze and the Moita plan by Gomes.

4) Materiality: These rules are used for qualifying urban space and its architecture by defining materials and details of urban spaces and volumes. They are used for reinforcing the sense of hierarchy in the urban space and improving legibility, thereby qualifying its symbolic and ambient values.

These design levels are related to scale and to the degree of detail of the solution. In most cases, they are addressed in the described order and, therefore, correspond to design development phases. However, as later experiments demonstrated, this is not necessarily the case, as the order may be inverted, particularly in the case of levels 2 and 3 when plans are generated in a bottom up fashion. Also, initial level 1 definitions (limits, basic geometries, and landmarks) are often questioned and reformulated when defining level 2 rules. Although the details of this reflective process will not be addressed in this paper, it became more apparent in the work of students during the design studios described in following.

3.2. Step 2: designing a design system

The methodology described above was tested in a design studio in which shape grammars were proposed as an auxiliary formalism to write and structure the rules of each of the methodological levels.

The design studio was organized in three steps. First, students were given background information on the context and provided with the fundamentals of the theoretical framework, namely pattern languages and shape grammars. In the first week, students were lectured on sustainable urban planning and design, including environmental, social, and financial aspects. Concerning the context, students were given handouts on regulations, standards, and the local master plan, as well as on population and economic data, including Michael Porter’s report on the Portuguese economy. In the second week, they were instructed in Alexander’s pattern language theory. For Alexander urban patterns are recurrent spatial configurations that are tied to specific ways of using urban space. They are defined in such a way that each pattern includes one component that describes the context in which it can emerge and another that contains instructions on how it can be designed. The aim for this language was to allow one to manipulate
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creatively its ingredients to develop an appropriate description of a design that fits the current context. The pattern language was presented to students as a means to define design goals and structure an urban program with a clear development vision. In the third week, students were lectured on shape grammars and given assignments involving simple abstract grammars. They were also provided with support readings on shape grammars. The idea was for them to use shape grammars to generate a design solution that matched the urban program later in the semester. As the emphasis was on the use of grammars for design synthesis, the mathematical principles and the technical apparatus of analytical grammars were explained but not demanded in the assignments. At the end of this introductory step, students were organized into groups of 3 to 5 students.

The second step dealt with the creation of a planning strategy for a wide developing area. The studied area was a vast region in Alentejo, Portugal, with strong development expectations due to the construction of a water dam. Work focused on a particular county and students could choose whether to expand existing villages or to build a new town in a strategically chosen place. For developing the strategy students had to take into account population data, Porter’s report, urban design guidelines, the Master Plan, and Alexander’s pattern language.

In the third step, students were asked to use the proposed methodology in the design of a flexible plan for a development of 5,000 inhabitants, either by expanding an existing village or creating a new town. They were requested to devise a set of rules capable of generating alternative solutions and then to illustrate its potential with a specific plan. Students had no background on shape grammars before this design studio and therefore it was their first attempt at designing with an articulated set of shape rules. Their reaction towards the new methodology was encouragingly positive.

In the studios, we avoided to be strict with things like notation so that students could use grammars in a somewhat intuitive way, that is, we did not want them to be caught up in technical details so that they could concentrate on how rules worked and could be applied. Writing rules for computer implementation is different than writing them for use by hand, when visual simplicity and understanding is crucial. Acknowledging this difference, students simplified the notation. For instance, instead of writing complex parametric rules that are mathematically elegant but hard to grasp visually, they preferred to list rule variations. Here we show rules as students wrote them because it gives a better idea of how they worked and used grammars, but the reader should be aware of the deviation from the usual grammar notation.
Due to space limitations, we concentrate our attention on two examples of urban plans produced in the studio, shown in Figures 4 to 12. We chose these plans to illustrate results because they are paradigmatic in terms of the use of shape grammars. One corresponds to the example of an expansion plan for an existing village developed in a top-down fashion, (Figures 4-7) while the other is the plan for a new town that follows a bottom-up strategy. (Figures 8-14) Let us call the teams who designed these plans Team 1 and Team 2, respectively.

Team 1’s plan is the example of a solution in which rules were extracted from the analyses of the territory in an attempt to describe how local villages had evolved. A group of five villages was considered for such purpose, although we focus on just one example. In this village, the urban fabric is formed after the division of polygonal areas that resulted from the crossing of preexisting roads and rural pathways. It is also clear in the aerial photo (Figure 4a) that territorial divisions correspond to property parceling and tend to be smaller towards the village center. From this analysis, students extracted rules to explain how the village might have grown, (Figures 4b to 4c) and then used them in the generation of the expansion plan. One rule (Figure 4d) determines the allowed distance between existing crossroads or squares, thereby permitting to define the location of new central points that become small activity nodes. From the analytical rules above, students defined a simple basic grammar composed of 7 generative rules. (Figure 5) Rules 1 to 5 make polygonal dissections and are used to create the street network and city blocks. Rule 6 applies to create plots by dividing blocks with lines traced perpendicularly from the main street on the larger side. This rule constrains plot width to specific values inferred from the analysis and then standardized to modulate construction. These 7 rules can replicate the urban development process and were used to expand the existing urban fabric in a similar fashion. (Figure 6) The derivation of a small expansion area according to these rules is shown in Figure 7. It is interesting to point out the similarity of this simple grammar to Stiny’s Ice ray grammar. (1977)

Although the basic generative rules were extracted from the analysis of existing villages, it is important to note that students separated the analytical process from the generative process. Therefore, they started the generative process by applying the inferred rules to the existing built structure, mainly roads and constructions, but felt free to disregard the existing parceling, when it collided with their design intents. So, although their generative process reproduces the existing urban morphology, tying polygonal dissections to the existing rural parceling would reinforce the logic of the proposed design system by matching design proposals with actual territorial data.
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Figure 4. Urban plan, Team 1: a – aerial photo of existing urban structure; b – territorial divisions corresponding to the street and road network; c – divisions corresponding to parceling; d – identification of the focal points of neighborhoods, where dm and dx represent the minimum and maximum distances between such points.

Figures 8-14 show the plan of a new town by Team 2. The plan was developed using a grammar created from scratch with the goal of generating a diverse and flexible urban tissue. Grammar rules were derived from spatial relations formed by arrangements of four blocks. These rules are then applied within a large matrix formed by geometric elements drawn from selected features of the territory, namely morphological features and visual lines connecting the site to a neighboring hill town. Structuring elements such as main streets and avenues are defined from this territorial interpretation and set the boundaries of the town’s neighborhoods. Figure 8 shows initial sketches of the plan, in which, straight lines are aligned with viewpoints towards the existing hill town. Curved and irregular lines represent preexisting structural elements such as a national road, the water front, and hill ridges. Rectangles depict main public buildings. Circles define the distances among future squares that will become the activity centers of different neighborhoods. These rules that define the structuring elements of the plan were not explicitly drawn but are implicit in students’ sketches.
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**Rule 1**

\[ d \leq 21m \land d > w \]

**Rule 2**

\[ 6m \leq w \leq 30m \land w = 6m + (3n)m \quad n \in \mathbb{N} \]

**Figure 5.** Urban plan, Team 1: generation rules.
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Figure 6. Urban plan, Team 1: example of a solution generated by recursive application of the rules in Figure 5.

The plan is completed using rules that fill in the structuring geometry with arrangements of four blocks formed by combining two different kinds of blocks, named TA and TB. (Figure 9) Each arrangement has three blocks of type TA and one block of type TB. The blocks are placed at a certain distance from each other and the gaps in between become streets. (Figure 10a) A referential axis reference permits to align block arrangements with each other and with structuring geometries. Other rules are then used to widen the street between blocks when they include commercial facilities. (Figure 10b) The recursive application of these rules permits the incremental growth of the plan and guarantees flexibility as there are many ways in which rules may be applied. (Figure 11) The plan foresaw the incremental growth of the town in distinct phases as shown on Figure 12. The plan shown in Figure 13 represents a possible solution that
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could result from the recursive application of the rules. Due to the irregular shapes of the arrangements of blocks, rule application creates small squares. The development of this plan follows a bottom-up approach by first defining the urban units and then the street network as a result of the recursive addition of block arrangements. After generating a solution, students felt a need for having a larger square in each neighborhood and, therefore, created a rule that subtracted one block to create such a square, (Figure 14) at specified distances from each other. The plan’s structuring geometric elements defined the boundaries of neighborhoods by constraining the application of block placing rules to the enclosed areas. The plan also included rules for characterizing the public space of neighborhoods differently by manipulating material features.

Figure 7. Urban plan, Team 1: derivation of urban fabric according to the rules in Figure 5.

Both plans show a particular interest in developing well-defined neighborhoods following Alexander’s patterns that students had chosen to include in their urban programs, namely, “14-identifiable neighborhood,” “15-neighborhood boundary,” and “28-eccentric nucleus.” Students used strong hierarchic principles to create such identifiable neighborhoods. The rules that guarantee these principles were applied during the development of basic geometries and grids, sometimes as the result of an interpretation of preexisting elements that were incorporated into the design.

For instance, in Team 2’s plan, the boundaries of neighborhoods were defined by the surrounding larger straight roads, and each neighborhood had an eccentric nucleus defined by the placement of public buildings followed by the creation of a public square. (Figure 8) The surrounding streets were created following visual lines linking selected preexisting territorial landmarks or topographic features like contour levels or ridge lines. The placement of public buildings followed the identification of territorial landmarks that determined the location of eccentric nucleus and complied with rules that constrained the distance between nucleuses. The instantiation of these patterns corresponds to level 1 (territorial
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landmarks) and level 2 (basic geometries) in the methodology. Neighborhood identity was then reinforced by applying rules to form city blocks and define the urban grid and by applying rules to create public squares near public buildings. These rules correspond to level 3 in the methodology. Finally, the use of different materials to characterize different neighborhoods, (level 4) completed the process of defining identifiable neighborhoods.

This experiment consolidated and detailed the design methodology. Also, it showed that shape rules could be used for designing a flexible urban plan while maintaining strong aesthetical values. Nevertheless, another experiment was necessary to test the planning efficacy of this approach. By efficacy we mean the ability of the plan to set clear ordering principles while remaining flexible to adjust to variations in the context and to permit future designers to reinterpret the same context when developing detail plans. This could be done by generating alternative solutions for sections of the plan using the same rules or by developing detailing rules.

![Figure 8](image8.png)

**Figure 8.** Urban plan, Team 2: left – existing road (a) and the tracing of main streets by linking selected existing territorial landmarks (b) and by following topographic features (c); right – the placement of public buildings is constrained to guarantee that they are within a walking distance from each other.

![Figure 9](image9.png)

**Figure 9.** Urban plan, Team 2: Two types of blocks with different dimensions constitute the basic units of the urban fabric.
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Figure 10. Urban plan, Team 2: a – Derivation of two clusters of four blocks; b – Rule for widening a street in front of a commercial space.

Figure 11. Urban plan, Team 2: Tree diagrams showing rules for combining sets of four blocks to form the urban grid. In each diagram, the top is the left-hand side of the rule whereas leaves are right-hand sides. Note how this simplification represents a deviation from the conventional rule notation.
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**Figure 12.** Urban plan, Team 2: Sequence showing the incremental implementation of the plan following the rules.

**Figure 13.** Urban plan, Team 2: Detail of the final plan obtained after applying rules for dividing the blocks into plots, drawing sidewalks, placing public buildings, etc. The circle calls the attention for a square generated by subtracting a block.
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Figure 14. Urban plan, Team 2: a – Rule for subtracting a block and creating a square near a public building; b – The square created by block subtraction, circled in Figure 13.

3.3. Step 3: using a design system

In the following year, to simulate real-world conditions and oblige students to consider urban ordering and flexibility at different scales, work was structured in three parts: theoretical knowledge acquisition and urban analysis, urban plan design, and detail plan design. After analyzing the context in its multiple aspects, students were asked to design an urban plan for a large expansion area on the northern sector of a town with approximately 25,000 inhabitants. Then they were requested to develop a detail plan based, not on their own urban plan, but on an urban plan designed by a different team. In this stage, the most promising urban plans were selected and teams were randomly assigned to them and then given copies of the assigned plans, including its rule set and instructions on how to apply it. The detail plan should be developed for an area not bigger than half of the area of the urban plan in order to guarantee that there would be more than one group working on the same urban plan. The idea was to generate alternative solutions within the limits set by the larger plan.

In Figures 15-16 we show an example of an urban plan developed by Team 3. In this plan the main concern was the creation of identifiable neighborhoods and so rules were created to characterize each neighborhood. (Figure 15) Such characteristics were inspired in Alexander’s urban patterns, namely “identifiable neighborhood”, “neighborhood boundary”, “activity nodes”, “shopping street”, “main gateways” and “small public squares.” In a way, this plan turns some of Alexander’s patterns into a system of shape rules forming a shape grammar, and applies this grammar to a specific urban context.
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thereby producing one possible solution. Figure 16 shows the rule application sequence that led to the final solution. Figure 17 shows a detail plan developed by Team 4 for the Southern sector of Team 3’s urban plan. The detail plan reveals the order imposed by the urban plan, specifically its vision of a series of interrelated neighborhoods. However, the design underlying the detail plan is an alternative solution obtained from the urban plan’s rules. The aim of guaranteeing order and flexibility is clearly achieved in this detail plan. Although the aim of creating distinct neighborhoods was reinforced with additional rules for defining materials aspects, order and flexibility were not compromised.

Figures 18-19 show another urban plan, designed by Team 5. It resembles the plan designed by Team 3 because it also results from combining rectangular urban units. In this case, units can be divided into four or three city rectangular blocks parametrically defined according to an underlying grid (not shown.) Units are qualified differently by mixing different uses, thereby creating a diverse and rich urban environment. Figure 18 shows the rules for generating units composed of four blocks (Rules 1-5) and three blocks. (Rules 6-10) The latter are used for blocks with public buildings that require larger plots and wider public spaces. Figure 19 illustrates one possible solution derived from the application of these rules.
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Figure 15. Urban plan, Team 3: selected rules. In some cases, for the same left-hand side there is more than one right-hand side. Note how this represents a deviation from the conventional parametric notation that students used to show multiple rules in a visually clearer way.

Figure 16. Urban plan, Team 3: Example of an urban plan generated following the rules in Figure 15.
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**Figure 17.** Detail plan by team 4 generated for the southern half of Team 3’s urban plan using its rules, but following a different rule application sequence.
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At the end of the semester, students were asked to answer a short questionnaire, conceived to curb subjectivity and find out which difficulties they had faced in applying the proposed rule-based methodology. The questions focused on the issue of flexibility and on the use of patterns and shape rules. This allowed for an introspective analysis of the resulting plans and helped to refine the methodology. The majority of students strongly supported the use of the proposed methodology. They said that working with a clear methodology helped them to structure the design process and cope with the inherent complexity of urban design. They also said that the use of patterns was helpful in establishing programmatic goals and that the use of grammars was effective for generating flexible plans. Some students said that they experienced difficulties in devising explicit rules. The ones who said they experienced greater difficulties were those whose plans were less flexible and had more complicated rules. In fact, the analysis of plans shows that the most flexible plans were those based on simpler, clear rules. Some students also expressed concerns regarding where to draw the boundary between rigid and
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flexible features of the plan. Most agreed that the structuring guidelines should be fixed because they were bound to territorial features, and the definition of urban units should be flexible because it depended on more transient features such as population, policies, and the economy. Generically, one can say that the larger the scale of design features the more definitive they should be and the lesser the flexibility allowed.

Students also agreed that use of one solution to illustrate the potential of their rules improved the understanding of a plan’s qualities and the effect of some rules. This is partially so because students only made explicit rules that they developed purposefully to respond to the flexibility requirement, mainly rules for defining urban grids and units. Other rules were just implicit in the plan, namely rules for defining the structuring geometric guidelines, because they saw these as fixed and dependent on contextual features. However, they could use such rules in the design of a plan for another site, and so, we may say that the plans have explicit and implicit rules. Finally, students who used the rules developed by other students said that it was difficult to keep track of all the contextual information needed for triggering the rules and tedious and time-consuming to apply them without a grammar interpreter. Despite the difficulties in following other students’ rules, the detail plans clearly show an underlying order defined by the larger plan and individual expression, at the same time, due to the freedom of reapplying rules and creating additional rules.

Figure 19. Urban plan, Team 5: Example of an urban plan generated following the rules in Figure 18.
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4. Discussion

The analysis of results provided useful information on the advantages and limitations of the proposed methodology as well as on the use of patterns and shape grammars in urban design. Results showed the following advantages regarding the use of shape grammars:

a) Shape grammars produce urban plans with non-definitive formal solutions, while keeping a consistent spatial language. Grammar-based plans permit the generation of alternative solutions based on similar principles and embodying a common development vision.

b) Shape grammars provide plans with explicit and implicit flexibility, thereby giving future designers a wider degree of freedom in the development of final solutions.

c) The use of shape grammars in teaching provides students with a concrete methodology for approaching urban design and fosters the development of additional skills.

Results also pointed to directions for future work:

d) Grammar-based plans could be supported by computer programs to evaluate alternative solutions or to serve as a municipality planning instrument. The knowledge gathered from these experiments suggests that the use of a shape grammar interpreter would be a promising planning tool.

e) The use of too many rules can constrain operability and make the plan difficult to use. The exact relation between rules, the methodology, and operability still needs to be determined, though it seems to be closely related to the scale of the urban plan. The best plans had a very strong urban concept, which seemed to be strongly related to the clear definition of urban units, such as neighborhoods. Results suggest that having a strong theoretical framework helps students to identify the aims of rules and the whole plan. A real application of these design principles in practice could reinforce and refine this methodology, providing new insights into the importance of flexible design methods and tools for supporting urban design.

f) In most cases, shape rules were applied differently in different sectors of the plans, suggesting that different rule sets may be needed for different sectors if the site is big. This means that a large urban plan might require different detail plans for different sectors. In any case, it is clear that the rules of larger scale plans should not constrain smaller scale plans to the extent that it makes it impossible to generate different solutions at their level of detail, thereby limiting design diversity.
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g) The experiments showed that generating a complete solution following the devised grammar is an important because it allows the designer to gain insight into the potential outcome and future designers to apprehend the qualities of the plan.

5. Refined methodology

The undertaking of the experiments described above led to the refinement of the proposed methodology. The refined methodology has been used in the studio since 2005 and it foresees the semester divided up into the following 1+4 phases:

Phase 0 (1 week): Briefing. The goal of this phase is to present the problem and provide students with the necessary background knowledge, namely, urban design theory, shape grammars, and urban patterns. First, students are given one text on each of these topics and then asked to read and write a small text for each of them summarizing their understanding of the subject. Then, they are presented with the methodology and work from students in previous years, and.

Phase 1 (4 weeks): Analysis. The aim of this phase is to let students gain a deep understanding of the design context in its multiple aspects, such as social, economic, morphologic, typological, and so on. They are provided with: (1) current and historical cartographic information; (2) reports on the economic state of the region to identify problems and opportunities; (3) statistic data characterizing the population in various ways; (4) information on the local master plan, including zoning codes, transportation infrastructure, and urban indexes; and (5) urban regulations and standards, specifying things like the number of inhabitants required to foresee a certain public facility. In addition, there are two weeklong workshops, one on pattern languages, and the other on shape grammars that include a lecture, readings, and hands on exercises.

At the end of this phase, students are asked to hand in a brief describing their analysis of the context including topographic features, the population’s profile, and a survey of existing urban indexes, public facilities, urban patterns, and building types. The brief also includes an interpretation of how the urban fabric might have evolved using simplified grammar rules. This information is then carried on to the subsequent phase.

Phase 2 (2 weeks): Strategy. In this phase students are expected to systematize their analysis of the context, interpret the data collected previously, and summarize it into a program for the subsequent urban intervention. The goal is an adequate formulation of the design problem, based on the interpretation of the
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contextual data, to define a strategy, or in other words, a development vision. At the end of this phase, students are asked to hand in a brief with the program, and this includes: selected territorial landmarks, foreseen economic activity; projected population; planned zoning codes, transportation infrastructure, and urban indexes; required public facilities; and desired urban patterns, including building types. The last two items should be interpreted as ways of materializing on a lower scale (mainly the neighborhood scale) a generic development vision defined on a larger scale. Finally, students are asked to hand in a map of the site summarizing the program, on which hatches and icons are used to indicate the type and approximate location of programmatic features.

Phase 3 (4 weeks): Urban plan (1/2000 or 1/1000 scale, depending on the size of the site). In this phase, students are asked to produce an urban plan following the theoretical framework described previously. The plan should be produced according to the program synthesized in the strategy. They are asked to hand in a brief that simulates the regulating document for the intervention area, which would supposedly be used by the local town hall. At the end of this phase, students are asked to hand a brief – “the plan”—with the following elements: (1) an introductory written statements explaining the context, goals, and principles; (2) a location plan, showing how the proposed site plan fits into the surroundings; (3) diagrammatic plans showing urban indexes, zoning codes, the transportation network, and the distribution of uses, building types, and public facilities; (4) the set of rules to use in the generation of a solution; (5) an explanation of how the rules might be applied; (6) a particular solution generated after the rules to illustrate the potential outcome; and (7) a 3D digital or physical model of this solution. Items (4), (5), and (6) might include diagrammatic plans showing the application of rules on the following levels: territorial landmarks, basic geometries (structuring guidelines and grids), and urban units (blocks, plots, and volumes). The plan should clarify what is rigid and cannot be changed and what is flexible. Namely, they should clarify what can be changed by a different rule application on such levels.

Phase 4 (3 weeks): detail plan (1/500 scale). In this phase students will test the efficacy of the urban plan to achieve the desired goals by developing a detail plan for one of its sectors, which defines the material features of public space. As mentioned in Section 3.3, students can develop the detail plan for an urban plan developed by other students. In this case, Phase 4 needs to last longer, so that students can become familiar with the rules of the urban plan. This phase is divided into three sub-phases: selection and study of the intervention area, sketch and elaboration of the detail plan. At the end, students are asked to
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present elements equivalent to those presented after Phase 3, with the difference that the new elements describe the material aspects of public spaces (streets, square, parks, etc.) and the confining façades.

The studio lasts for 14 weeks but the exact breakup of time among the phases may vary according to the academic calendar. It has been taught in the 1-4-2-4-3 week format just described, but also in other formats such as 1-3-2-4-4 or 1-3-2-4-4, and even 3-3-4-4 and 4-3-4-3 when Phase 0 was merged with Phase 1. The specific format seems to have no impact on the results, as grade distribution is about the same. In any case, work is developed in teams of 3 to 5 students.

6. Conclusion

Research was undertaken with the aim of showing whether urban patterns and shape grammars could be used in a methodology for developing flexible urban plans. It showed that designers’ process encompasses two main tasks that may, nevertheless, overlap in time: one task aiming at the analysis and interpretation of the context to produce an urban program, and another task dealing with the development of the plan. It also showed that designers develop rules concerning four levels: territorial landmarks, basic geometries, urban units, and material features. This methodology was then tested in two subsequent design studios and then refined.

Results show that shape grammars can produce plans with non-definitive formal solutions but with explicit and implicit flexibility. Pattern-based urban programs and grammar-based urban plans allow for the generation of alternative design solutions, while respecting a consistent spatial language and a common development vision. These characteristics increase the efficacy of the plan and may extend its lifespan as they enhance the capacity of adjusting to contextual changes. It also imposes less constraints when a designer has to work within the framework given by a plan by other designer, as s/he may manipulate its rules to generate an alternative design that suits her/his interpretation of the context. This reinforces the potential of the proposed approach in a real planning environment.

The methodology includes four subtasks: analysis, strategy, urban plan, and detail plan. In analysis the designer examines the context to collect various type of information concerning the site and the population and identify existing territorial landmarks, urban patterns and shape rules. In the strategy the designer interprets the collected data to formulate the problem and generate the urban program, in which s/he selects territorial landmarks and proposes new patterns and urban typologies, among other things. In the urban plan, the designer specifies shape rules for materializing patterns and illustrates their application
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in the generation of a plan that matches the program. Finally, in the detail plan, the designer sets the rules for dealing with the materials aspects of urban space.

This methodology has been used in the teaching of an urban design studio by making each subtask correspond to a methodological phase. These phases are not strict as students may reformulate the work of one phase in the subsequent one. For instance, they may reformulate the program while developing the urban plan, but need to explain why. Results show that this methodology helps students to define clear aims while designing. They also suggest that rules can be created on each methodological level autonomously, though not independently, to guarantee the unity of the whole. Results also show the advantages of following this methodology in developing a rule-based approach to urban design that yields flexible plans.

This work sets the experimental and theoretical basis for the development of a real-world experiment to test the approach. Given the experimental results obtained so far, the potential of its application to practice looks promising. Future work will be concerned with this endeavor. However, the development of real applications needs to be preceded by studies aimed at finding ways of representing the set of solutions encoded by plans, as this is a practical requirement for approving them by a town hall. Questions that need to be answered at this level are: How can one appraise and approve a plan that is flexible and can yield multiple solutions? Can a set of shape rules and an illustrative plan generated by such rules be used objectively for this purpose? We believe that a set of integrated computer design support tools for urban design, integrating analytical, generative, and evaluative modules may lay down the foundation for solving the problem, and shifting paradigm from rigid layout plans to the flexible design systems. Ongoing research is concerned with expanding and detailing the methodology put forward in this paper and developing a computer platform to support the methodology. (Duarte et al., forthcoming)

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